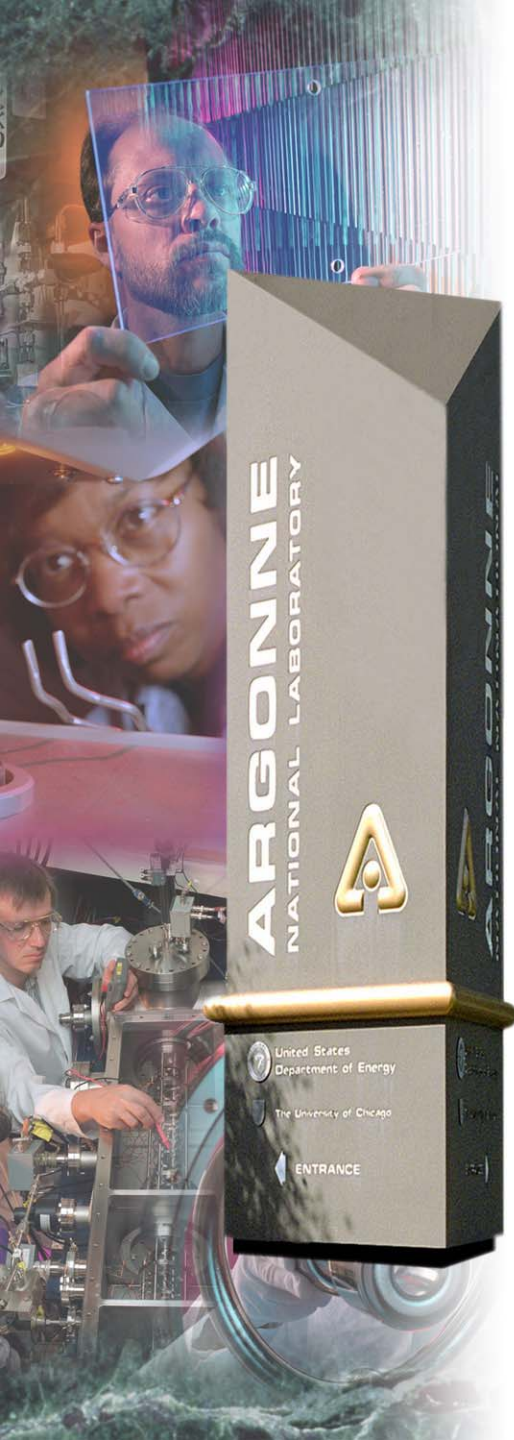


# ***Briefing on Produced Water White Paper***

***Presented by John Veil  
Argonne National Laboratory  
Washington, DC***

**DOE-NPTO Offices  
Tulsa, OK  
December 2, 2003**



**Argonne National Laboratory**  
*Operated by The University of Chicago  
for the U.S. Department of Energy*



## *Topics for Discussion*

- Purpose of white paper
- What is produced water and what is in it?
- How much water is generated?
- Produced water management options
- Regulatory requirements
- Costs
- Areas for future research



# *Purpose of White Paper*



- DOE wants a background document on produced water
  - Provides baseline for year 2003
  - Can serve as starting point for future research program

# *White Paper Provides Overview Level of Detail*

- DOE wanted product quickly
  - Needed product by late fall 2003
  - Funding did not arrive until August 2003
- DOE elected to fund just baseline study effort (\$50K) and not any of the expanded work options
- Paper contains more than 100 references that can be consulted for more details

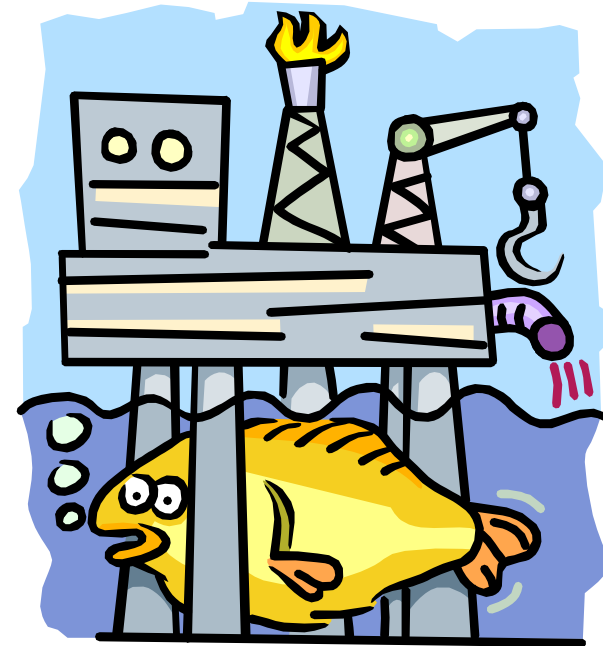
# *What is Produced Water?*

- Water that comes to the surface with oil and gas
- Contains many chemical constituents
- Concentrations vary widely by:
  - Geographic location
  - Geological formation
  - Type of production
  - Life span of well



# What Is In Produced Water?

- Key Constituents
  - Salt content (salinity, total dissolved solids [TDS], electrical conductivity)
  - Oil and grease
    - *Not a single compound but a composite of many hydrocarbons and other organic materials*
  - Toxicity from various natural inorganic and organic compounds or chemical additives
  - NORM
- Final disposition or use of produced water determines which constituents are of greatest concern

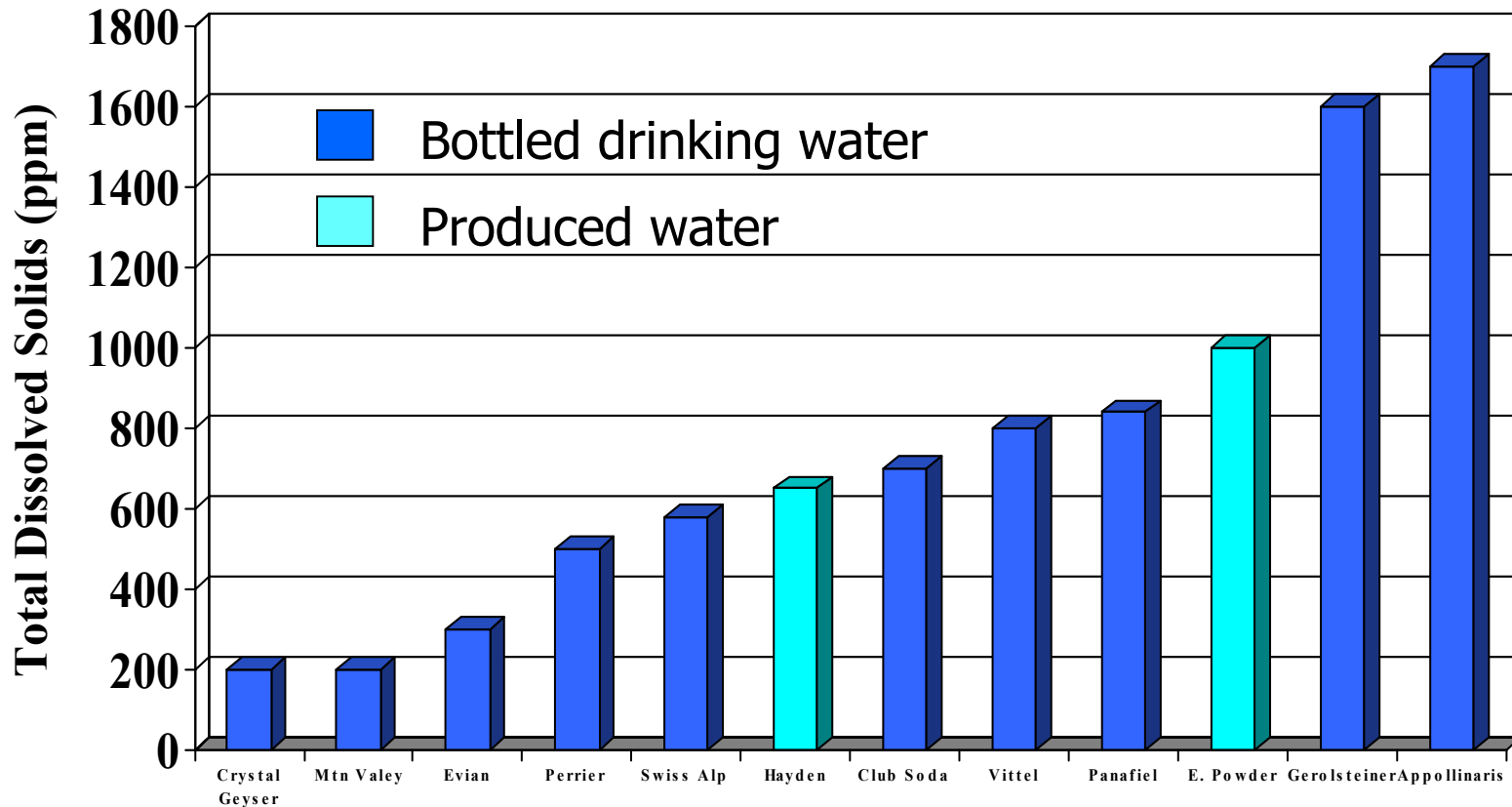


# *Potential Adverse Impacts of Produced Water*

- Can harm aquatic life when discharged at inappropriate locations or at excessive concentrations
  - Different impacts at different locations
- Can harm crops and soils if used for irrigation without proper consideration of salts and sodium
  - Same applies for spills
- Not all impacts are bad – more on beneficial uses later

# ***Produced Water Characteristics***

- Usually is salty
  - Chlorides vary from <1 to >200,000 mg/l



Source: S. DeAlbuquerque, ConocoPhillips



# Produced Water Volume

- Largest volume waste stream from oil and gas production
  - Worldwide estimate – 77 billion bbl/year (2003 SPE paper)
  - U.S. offshore – 0.2 to 1.2 billion bbl/year (no good estimates)
  - U.S. onshore (more than 850,000 wells)
    - 18 billion bbl/year (1995 API study)
    - 14 billion bbl/year (2002 estimate from recent inquiries)
      - Problems with missing data for many states
      - Estimated by multiplying historical water-to-oil ratio times the crude oil production
      - Does not account for gas and CBM wells

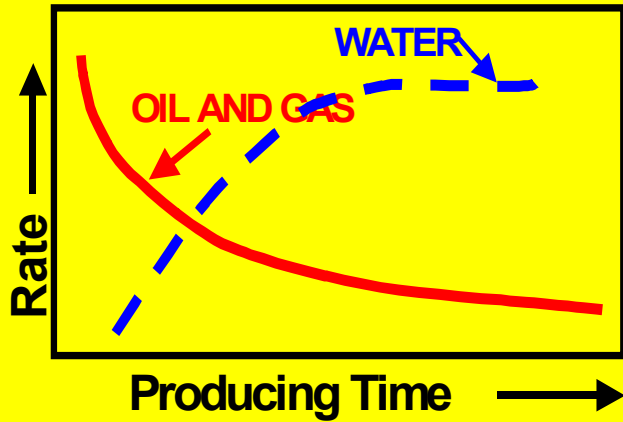
# Annual U.S. Onshore Produced Water Volume

State	1985 <sup>a</sup>	1995 <sup>b</sup>	2002 <sup>c</sup>	Source
Alabama	87,619	320,000	99,938	State
	97,740	1,090,000	813,367	State
Alaska	149	100	88	Estimate
Arizona	184,536	110,000	90,331	Estimate
Arkansas	2,846,078	1,684,200	1,290,050	Estimate
California	388,661	210,600	133,005	Estimate
Colorado	No data available	76,500	48,990	Estimate
Florida	1,282,933	285,000	212,098	Estimate
Illinois	No data available	48,900	34,531	Estimate
Indiana	999,143	683,700	1,174,641	State
Kansas	90,754	3,000	2,411	Estimate
Kentucky	1,346,675	1,346,400	1,079,805	State
Louisiana	76,440	52,900	33,207	Estimate
Michigan	318,666	234,700	286,532	State
Mississippi	No data available	100	1,200	State
Missouri	223,558	103,300	104,501	Estimate
Montana	164,688	61,200	51,191	State
Nebraska	No data available	6,700	2,765	Estimate
Nevada	445,265	706,000	112,934	State
New Mexico	No data available	300	844	State
New York	59,503	79,800	78,236	Estimate
North Dakota	No data available	7,900	6,416	State
Ohio	3,103,433	1,642,500	1,252,870	Estimate
Oklahoma	No data available	2,100	5,842	State
Pennsylvania	5,155	4,000	3,293	State
South Dakota	No data available	400	275	Estimate
Tennessee	7,838,783	7,630,000	5,031,945	State
Texas	260,661	124,600	84,791	Estimate
Utah	No data available	300	550	Estimate
Virginia	2,844	6,000	4,284	Estimate
W. Virginia	785,221	1,401,000	2,119,394	State
Wyoming	20,608,505	17,922,200	14,160,325	
TOTAL				

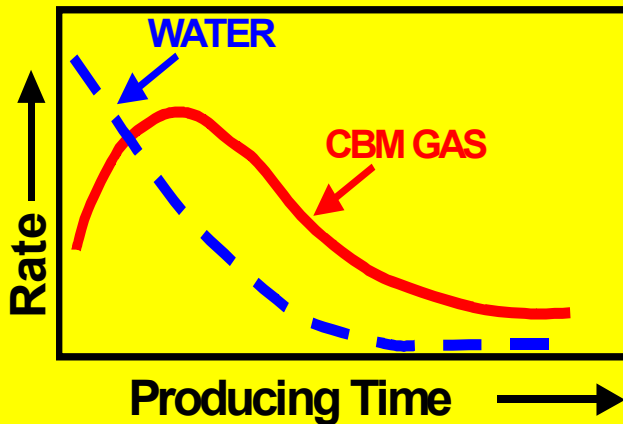
## ***Relative Volumes from Oil, Conventional Natural Gas, and Coal Bed Methane***

- Oil has greatest volume
- Conventional natural gas has relatively little
- Coal bed methane starts out high but declines

# *Produced Water Volume Changes Over Time in a Well and a Field*



Conventional oil and  
gas well



Coal bed methane  
well

# *Ratio of Water to Oil*

- Worldwide estimate – 2:1 to 3:1
- U.S. estimate – 7:1
- Many older U.S. wells have ratios  $> 50:1$ 
  - This often determines profitability of well



# ***Factors Affecting Produced Water Volume***

- Type of well
- Location of well within reservoir
- Type of completion
- Type of water separation and treatment facilities
- Presence or absence of water flooding
- Loss of mechanical integrity of well

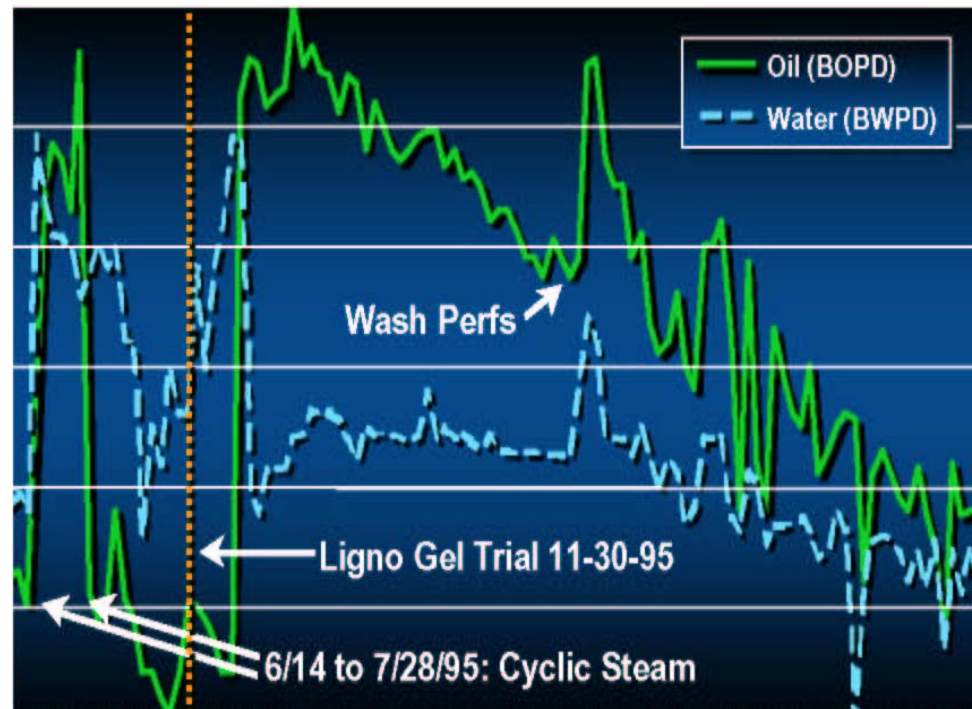
# ***Produced Water Management Options – Follow Waste Management Hierarchy***

**Try to follow the most environmentally friendly option first. If not practical or economical, then go to next best option.**

- **Waste minimization**
  - Reduce generation of waste
  - Reduce exposure of material to locations where it can cause a problem
- **Recycle/reuse**
  - Put the material to another use
- **Disposal**
  - With or without treatment

# Waste Minimization

- Reduce produced water production
  - Mechanical blocking devices
    - Packers
    - Plugs
    - Cement
  - Water shut-off chemicals
    - Polymer gels
    - Microbial products
    - lignosulfonate



Source: G. Thakur, ChevronTexaco



# *Waste Minimization (continued)*

- Manage water without bringing it to surface
  - Downhole oil/water separators
  - Downhole gas/water separators
  - Dual completion wells (downhole water sink)
  - Seafloor separation



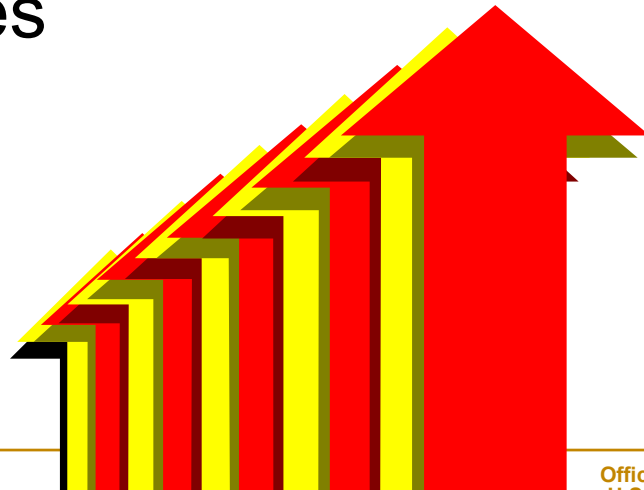
# ***What Is A Downhole Oil/Water Separator (DOWS or DHOWS)?***

- Tool that mounts in bottom of well and separates oil from water
- Oil is pumped to the surface
- Water is pumped to injection zone without coming to surface



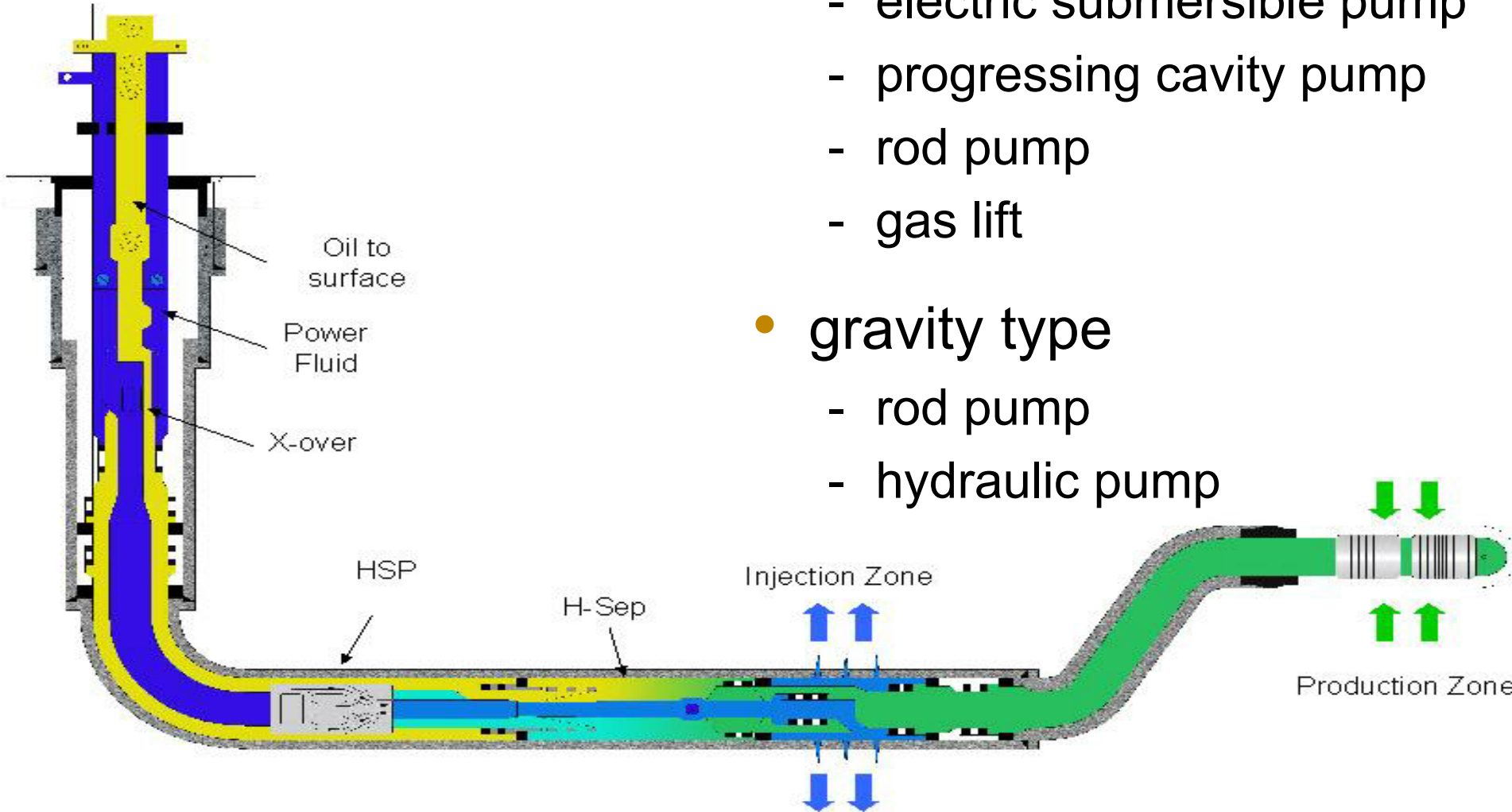
# *Advantages of DOWS*

- reduces produced water handling costs
- may increase oil production from individual wells or from a field
- reduces opportunity for contamination of drinking water supplies



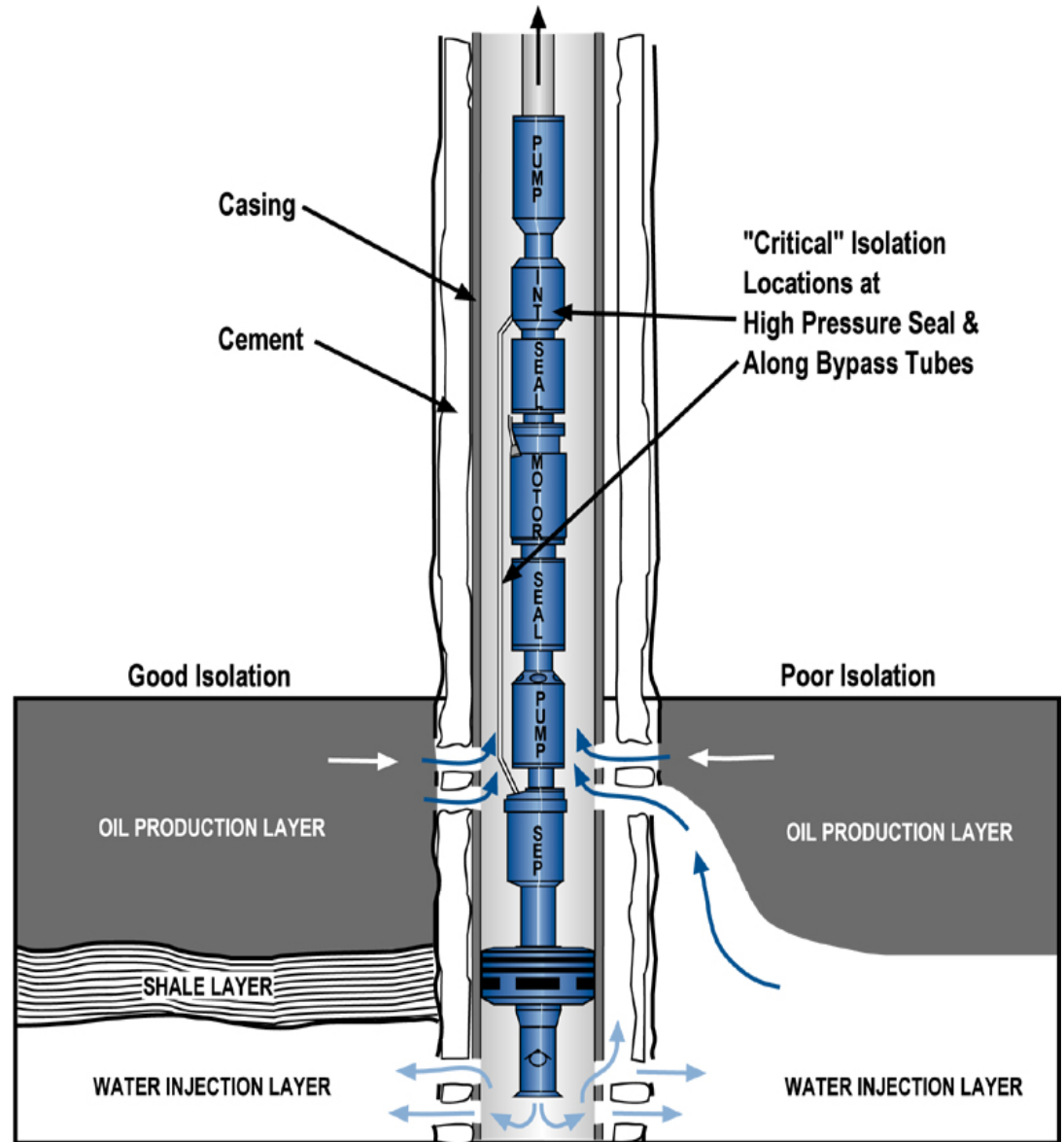
# Two Types of DOWS

- hydrocyclone type
  - electric submersible pump
  - progressing cavity pump
  - rod pump
  - gas lift
- gravity type
  - rod pump
  - hydraulic pump



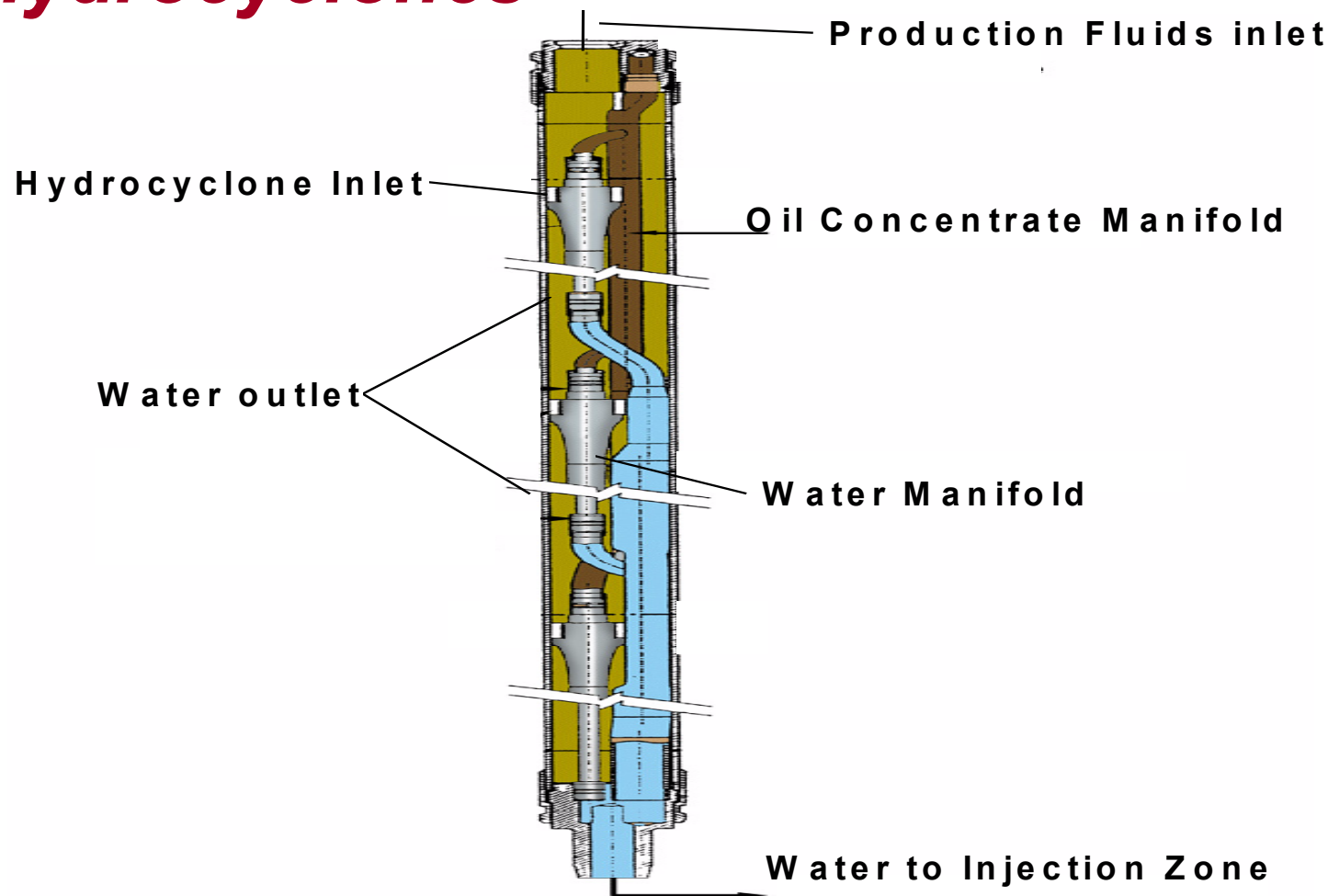
# Diagram of Hydrocyclone-Type DOWS

Source: Centrilift

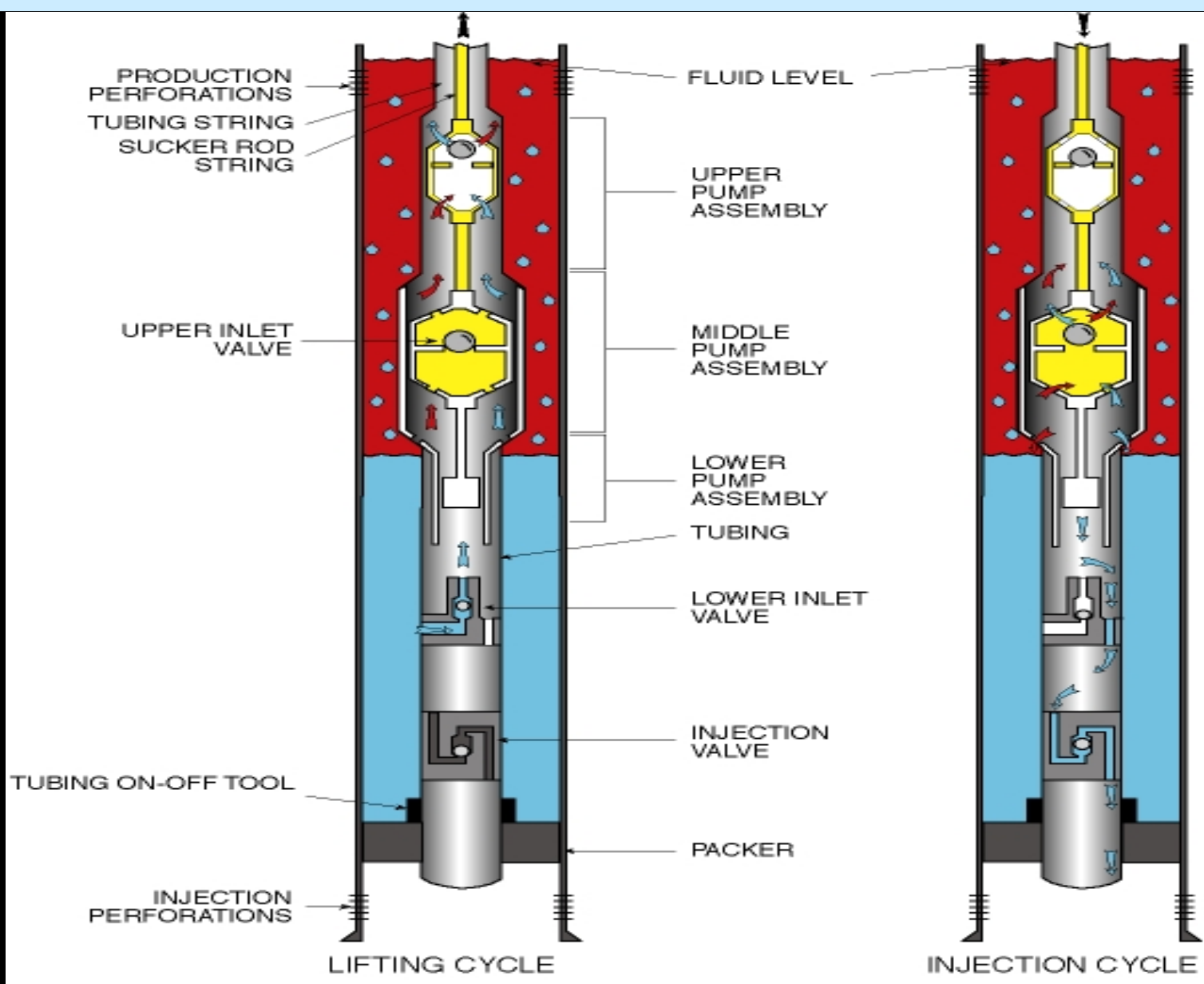




# *Hydrocyclone-Type DOWS with Multiple Hydrocyclones*

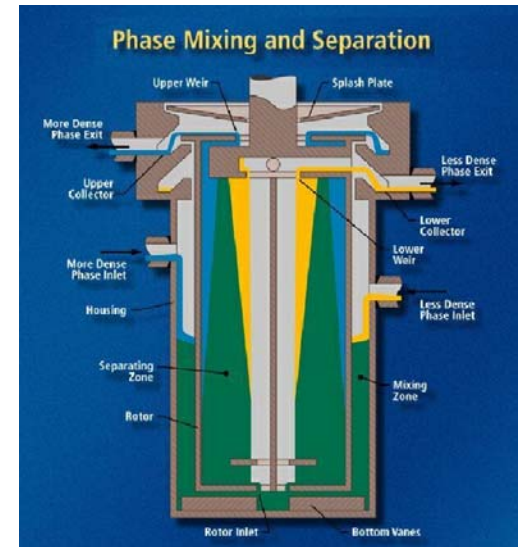


# Gravity-Separation DOWS with Rod Pump Source: Texaco



# Centrifugal DOWS

- Oak Ridge National Laboratory is working to determine the applicability of an existing nuclear industry device for oil/water separation
  - centrifugal contactor/separator for liquid-liquid extraction applications
- Trying to demonstrate separation capability over a range of recovery conditions
- Plan to design an optimized device based on test results and hydraulic modeling
- Major service company is working on a centrifugal-type DOWS prototype



Source: Oak Ridge National Laboratory

Note: This is the original configuration; proprietary improvements have been made to the feed system to minimize mixing.

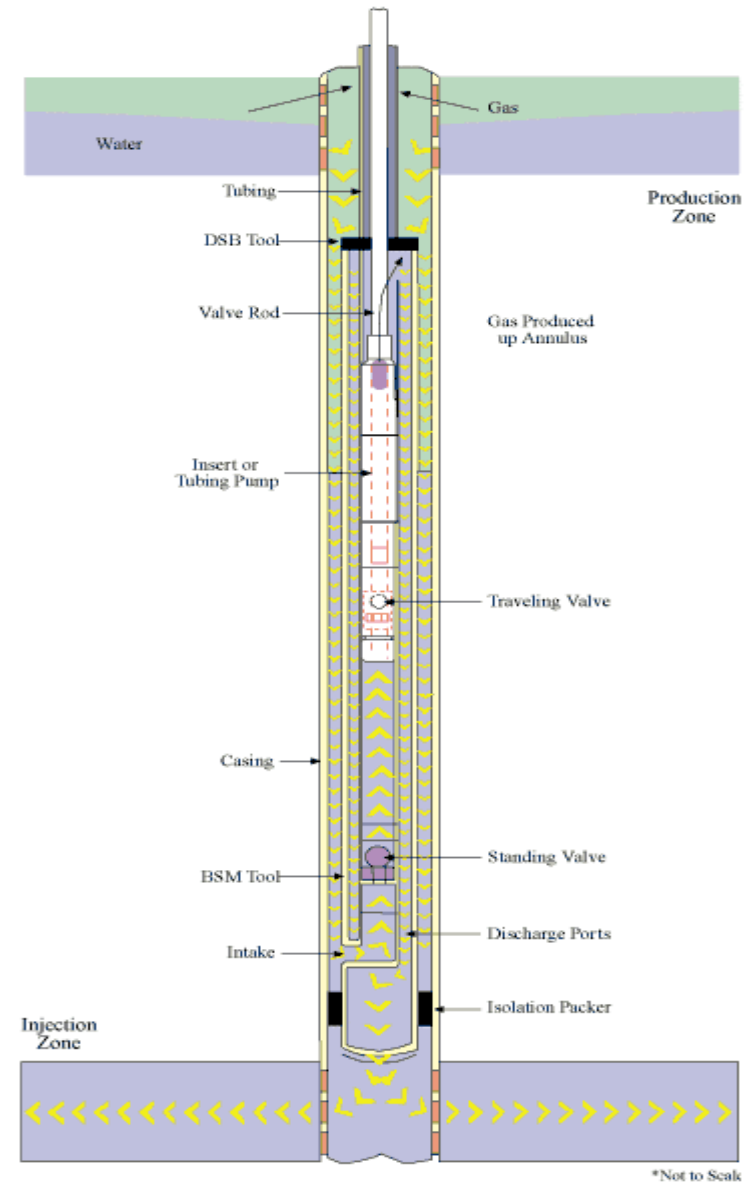


# Downhole Gas/Water Separators

- Used more frequently than DOWS
- Described in 1999 study available from Gas Technology Institute

**Source: Gas Technology Institute website  
([www0.gastechnology.org](http://www0.gastechnology.org))**

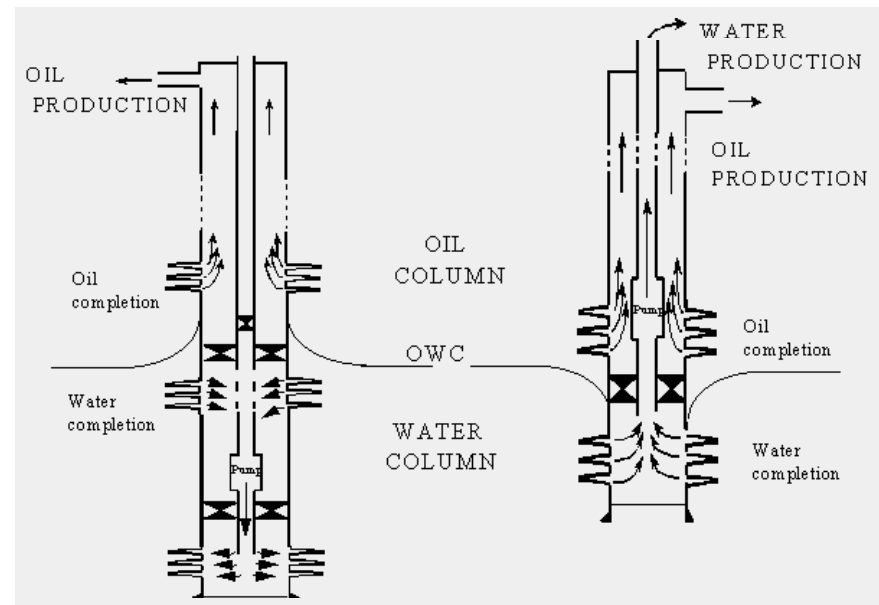
**Figure 1: Schematic of Reverse Flow Injection System**



# *Downhole Water Sink*

- Uses dual completions
  - One at depth of strong oil production
  - Other at lower depth where water is produced
  - Separated by packer
  - Water collected below packer is injected and kept away from producing zone or is lifted to the surface

**Source: A. Wojtanowicz,  
Louisiana State University**



# ***SUBSIS (Subsea Separation and Injection System)***

- Not a DOWS, but separates oil and water at sea floor
- Developed by ABB Offshore Systems
- Very large size (350 tons, 3 m x 10 m)
- Full operation started in August 2001 in 350 m depth off the coast of Norway
  - Water was injected from sea floor to dedicated injection well
  - Flow rate: 20,000 bpd avg. and 60,000 bpd max.
  - Resulted in incremental oil production of 2.5 million bbl

# SUBSIS System

**Source: ABB  
Offshore  
Systems**



Pioneering  
Science and  
Technology



# Recycle/Reuse

- Injection for enhanced recovery

- **California**

- *Nearly 25,000 produced water injection wells*
- *1.8 billion bbl/year total injection*
  - 900 million bbl/year water flood
  - 560 million bbl/year steam flood
  - 360 million bbl/year injection for disposal

- **New Mexico**

- *5,036 wells permitted for enhanced recovery*
  - 350 million bbl/year
- *903 wells permitted for disposal*
  - 190 million bbl/year

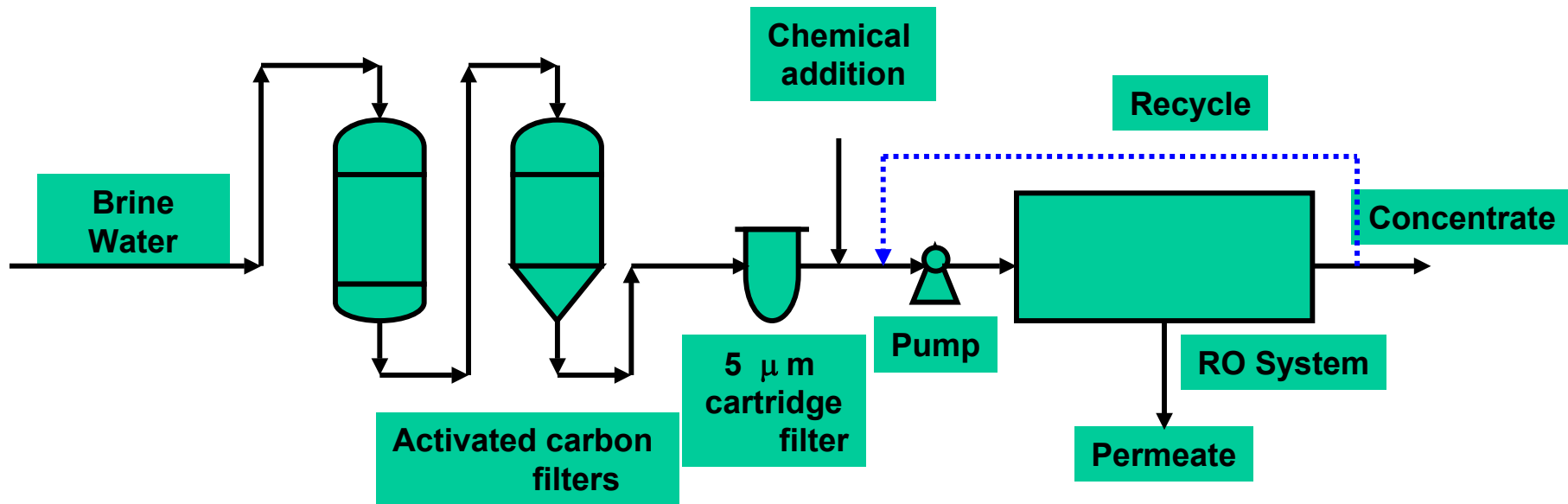


## Texas

- 38,540 wells permitted for enhanced recovery
  - 5.3 billion bbl/year
- 11,988 wells permitted for disposal
  - 1.2 billion bbl/year

# Recycle/Reuse (Water Supply)

- Aquifer storage and recovery
- Drinking water
  - Program under way at Texas A&M University to treat produced water for water supply
  - Current cost - \$0.80/bbl - \$1.30/bbl



# *Recycle/Reuse (Plants and Animals)*

- Agriculture/Aquaculture

- 480,000 bpd used for irrigation of fruit trees in California
- Several examples of successful irrigation of range land produced much more forage grass
  - *May need to add soil supplements*
- Tomatoes grown using produced water were smaller than those using drinking water (Wyoming)
- Tilapia fish raised in produced water grew larger than controls but some died (Wyoming)

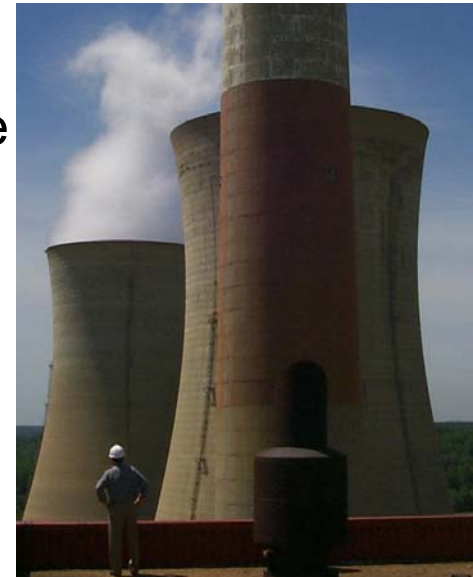
- Livestock watering (TDS is critical)

- Wildlife watering and habitat



# Recycle/Reuse (Industrial Uses)

- Use in oil field
  - Treated and used in drilling operation in New Mexico
  - Saves over 4 million bbl/year of fresh groundwater
- Power Generation
  - 360,000 bpd is further purified and used to make steam at a cogeneration facility in California
  - Recent NETL grant to study use as makeup for cooling towers
- Dust control
- Vehicle washing
- Fire control
- *See July 2003 ALL report for more details on reuse of CBM water*





# *Disposal*

Discharge



Injection



# *Basic Separation of Oil, Gas, and Water*

- Free-water knockout tank separates three phases
- Emulsions
  - Heater-treater
  - Demulsifying chemicals
- Onshore – pass through tank battery, then inject
- Offshore – discharge



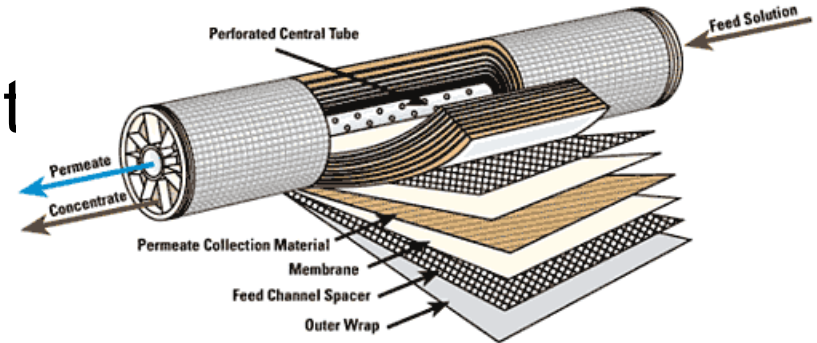
# ***Treatment before Injection***

- Make sure water is compatible with formation
  - Solids
  - Dissolved oil
  - Microbes
  - Corrosion sources
- Typically use various treatment chemicals
- May need filtration

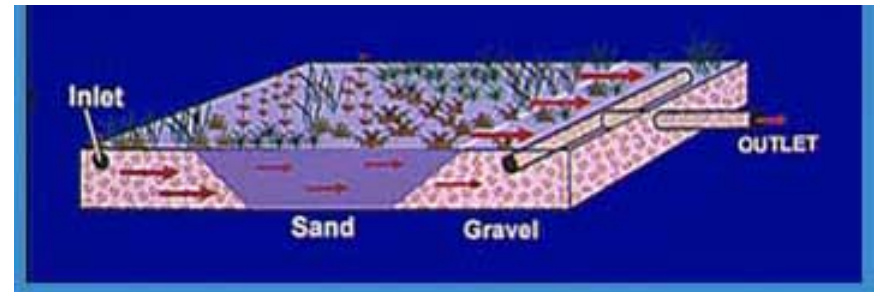


# Onshore Discharges

- Often need to remove salt or TDS
  - Reverse osmosis
  - Ion exchange
  - Electrostatic precipitation
- May employ biological treatment
  - Constructed wetlands



Source: Osmonics



# *Other Onshore Disposal Technologies*

- Evaporation via misting towers
- Freeze-Thaw Evaporation
- Evaporation ponds



Source: Western Pump & Dredge



# Produced Water Offshore Treatment Technology

- There are many types of produced water treatment used at offshore facilities
  - Primarily designed to reduce free oil and other dissolved organics in order to meet the oil and grease limit of 29 mg/l average and 42 mg/l maximum
- Oil and grease is a variable parameter
  - Free oil (large droplets, easy to remove)
  - Dispersed oil (small droplets)
  - Dissolved oil (difficult to remove)
    - *ORNL project to evaluate dissolved organics*
- Measurement of oil and grease depends on analytical method



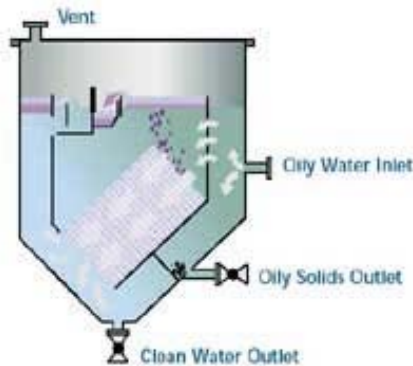
# *Analytical Issues for Oil and Grease*

- Measurement technique for oil and grease has changed due to phase-out of freon
- Newer methods measure different component of oil and grease and may not match up with standards based on older analytical method
- Different methods used in other parts of the world



Source: Turner Designs

# Separation Technologies



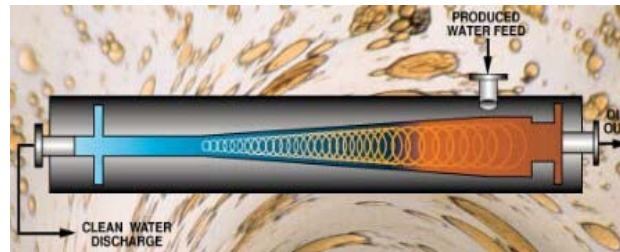
**Corrugated plate separator**

**Source: Natco**



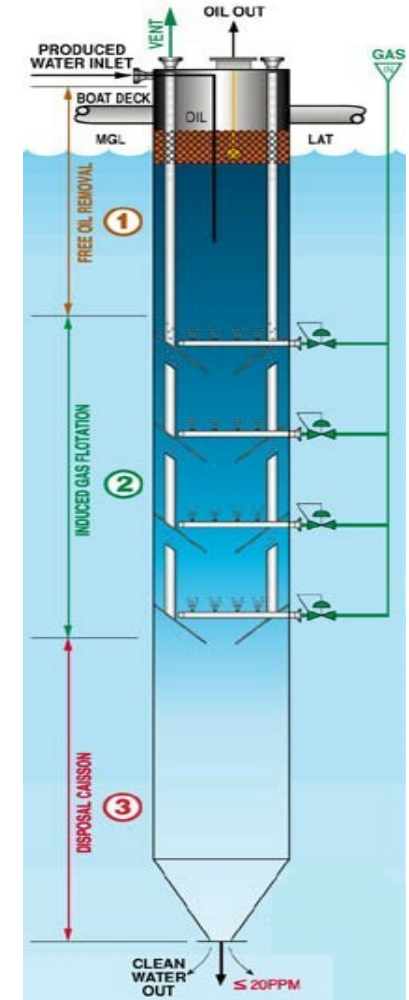
**Hydrocyclone**

**Source: Natco**



**Hydrocyclone**

**Source: Engineering Specialties**



**Flotation pile**

**Source: Engineering Specialties**



# Filtration Technologies



**Cartridge filter**

**Source: Twin Filter**



**Media filter**

**Source: Natco**

# Coalescer Technology

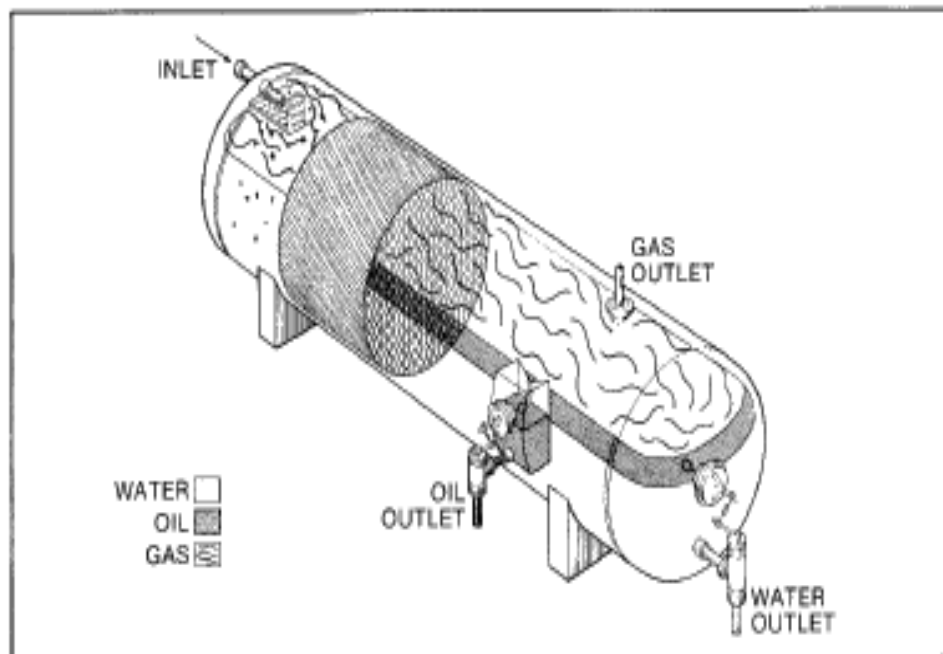
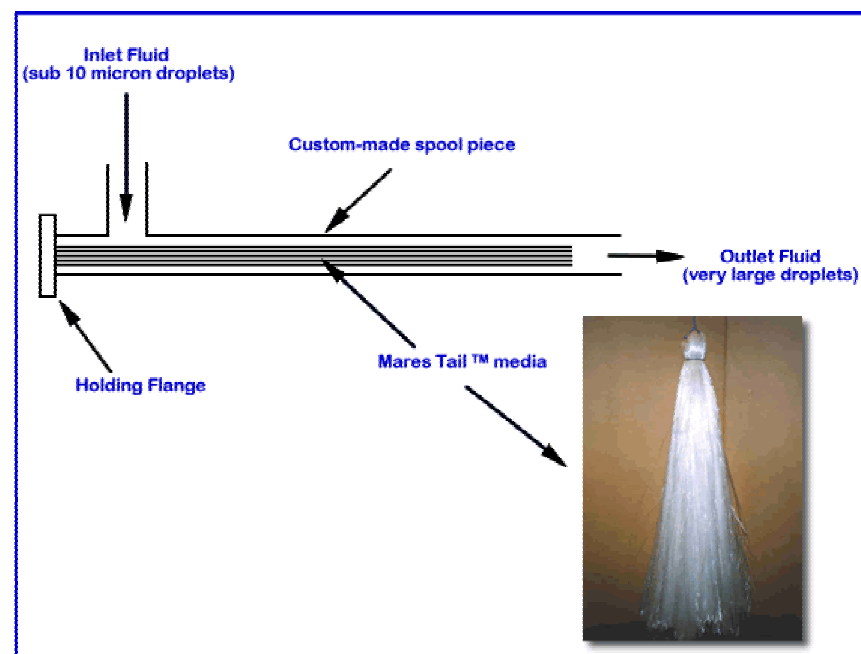


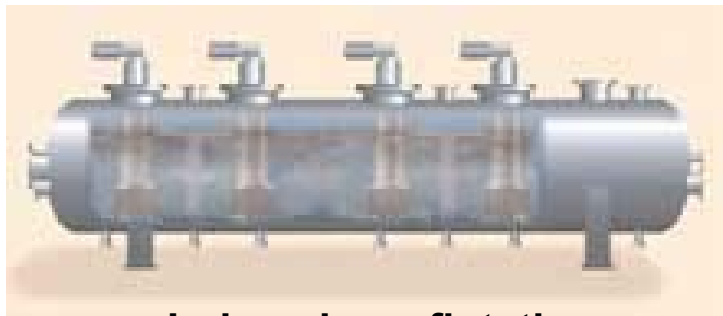
Figure 1. Cutaway view of PERFORMAX Coalescer

Source: Natco



Source: ERT Ltd.

# ***Flotation Technologies***



**Induced gas flotation**  
**Source: Natco**



**Dissolved gas flotation**  
**Source: Separator Specialists**



**Flotation cell**

# Extraction of Dissolved Organics

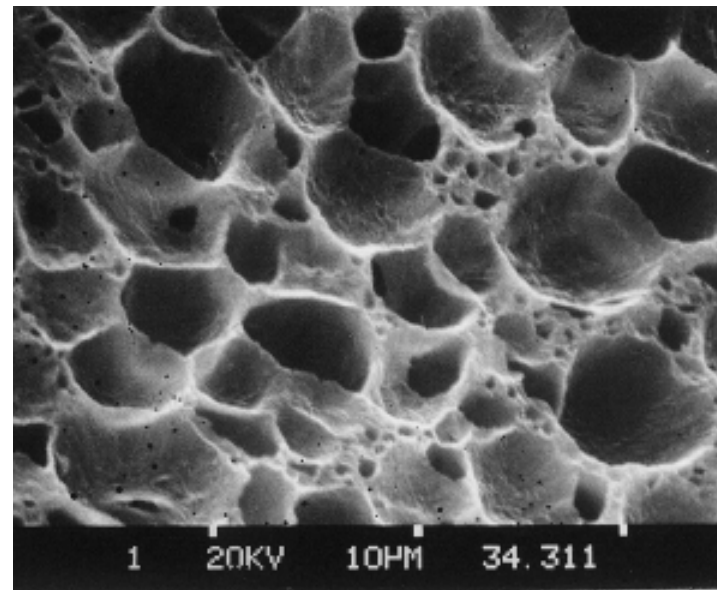
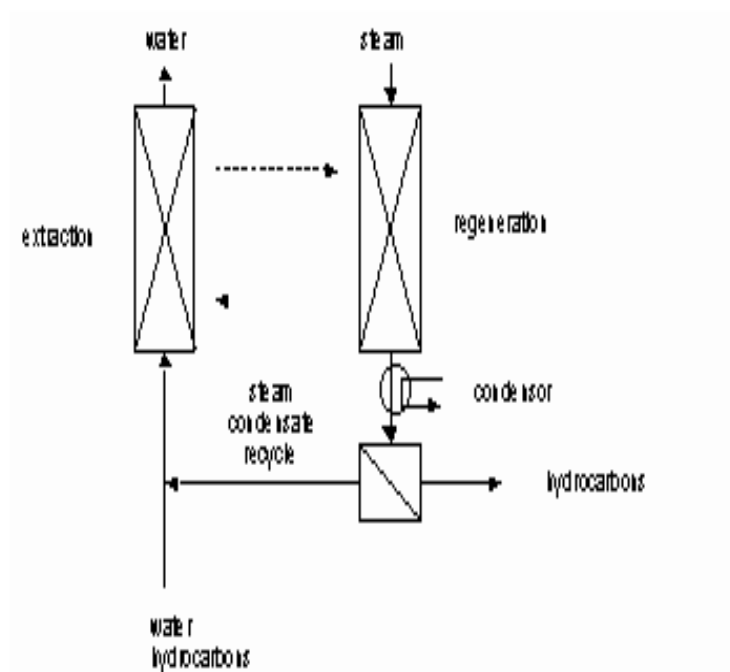


Figure 2: Schematic Overview of Macro Porous Polymer Extraction Process

Source: Akzo Nobel

# ***U.S. Regulatory Requirements for Discharging***



## **Laws**

- *Clean Water Act*

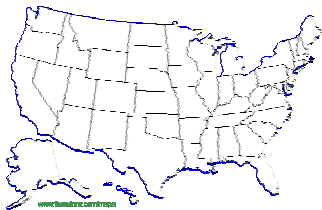


## **Discharge Regulations**

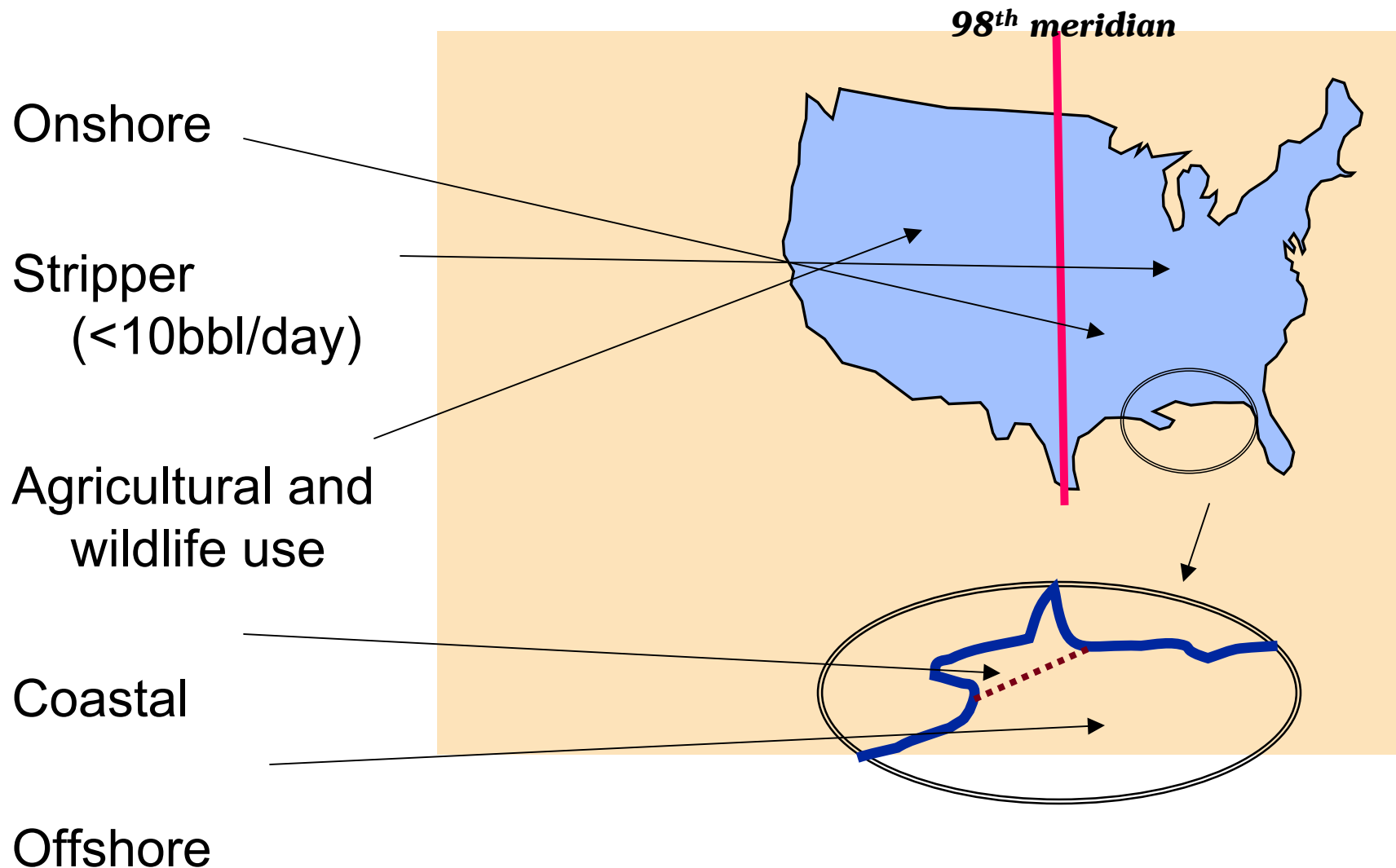
- *National Pollutant Discharge Elimination System (NPDES) program*
- *Effluent limitations guidelines (ELGs)*

## **Permits and Guidance**

- *Environmental Protection Agency (EPA) or delegated states issue NPDES permits for discharges*

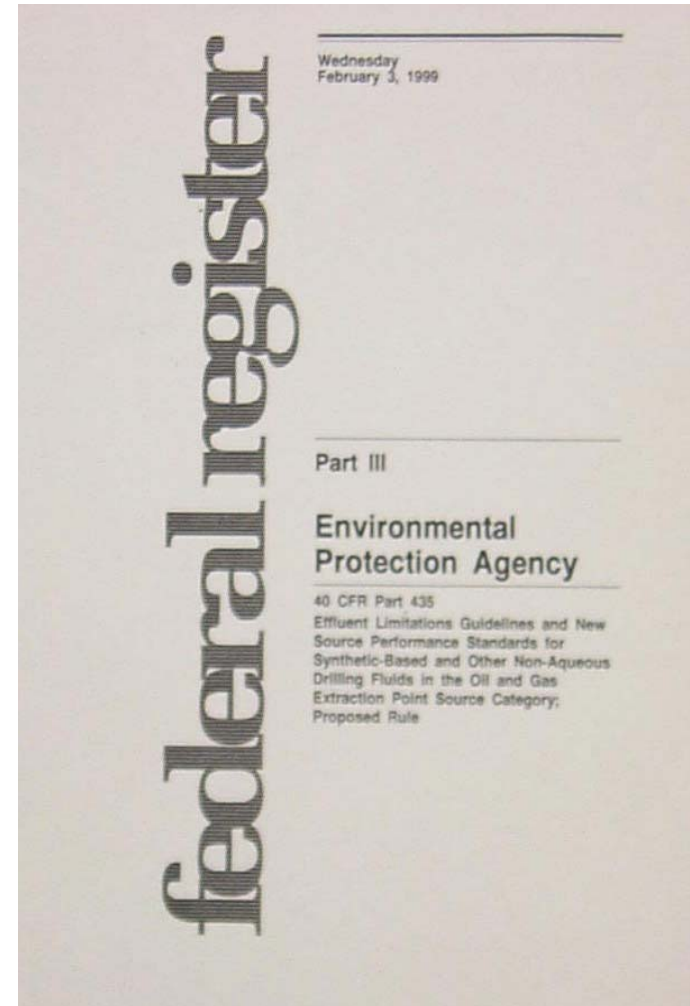


# ***EPA Oil and Gas Effluent Limitations Guidelines (ELGs) [40 CFR 435]***



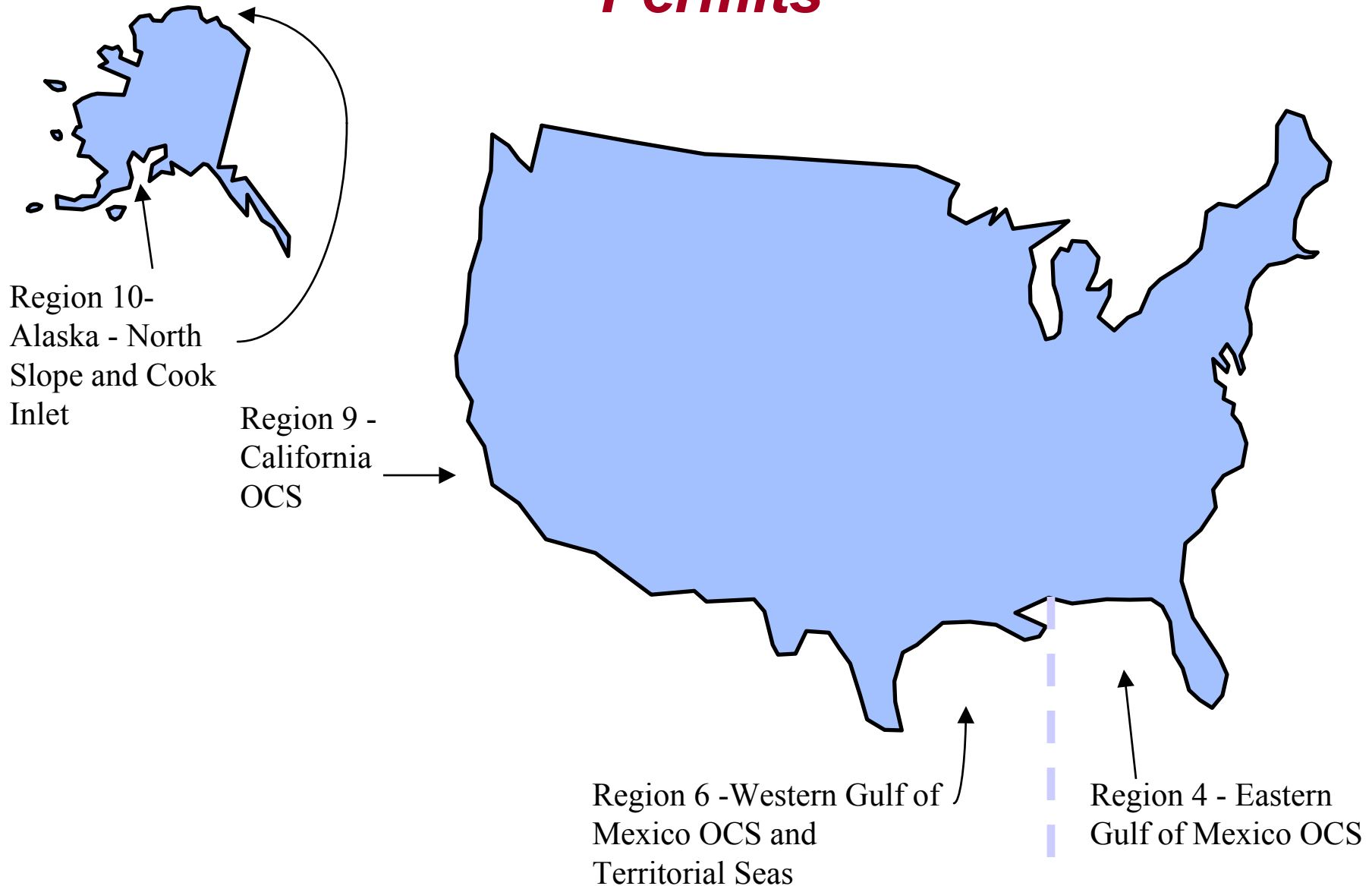
# Offshore and Coastal ELGs

- Best Available Technology (BAT) for offshore produced water:
  - Oil and grease limits before discharge
    - 29 mg/l monthly average
    - 42 mg/l daily maximum
- BAT for coastal produced water
  - zero discharge except in Cook Inlet, Alaska
  - Offshore limits are required there





# ***EPA Regions Issuing Offshore General Permits***



# *Other NPDES Permit Conditions*

- Discharge rate
- Best management practices (BMP) plan
- Toxicity testing
- Ecological testing
- List of chemical additives
- Extra chemical monitoring



# *Why Is Toxicity Testing Required?*

- Gives a biological indication of impacts of produced water and other production waste discharges on aquatic life
  - ELGs limit only oil and grease
  - Toxicity is an integrator of all other pollutants
- Combination of tests using different biological taxa improves regulator's confidence
  - Fish
  - Invertebrates
    - *Shrimp*
    - *molluscs*
  - plants



# ELGs for Wells Located Onshore

- Onshore subcategory
  - zero discharge
- Stripper subcategory
  - No national requirements
  - Jurisdiction left to state or EPA region
- Agricultural and Wildlife Use subcategory
  - produced water must have a use
    - *Water must be of good enough quality for wildlife, livestock, or other agricultural use*
    - *Produced water must actually be put to that use*
  - Oil and grease limit of 35 mg/l maximum



# ***U.S. Regulatory Requirements for Injection***

- Underground Injection Control (UIC) program can be administered by state agencies
- Must protect underground sources of drinking water from contamination by fluids that are injected
  - Requirements for:
    - *Well location and construction*
    - *Operations*
    - *Monitoring*
      - pressure
      - flow rate
      - volume
    - *Plugging and abandonment*



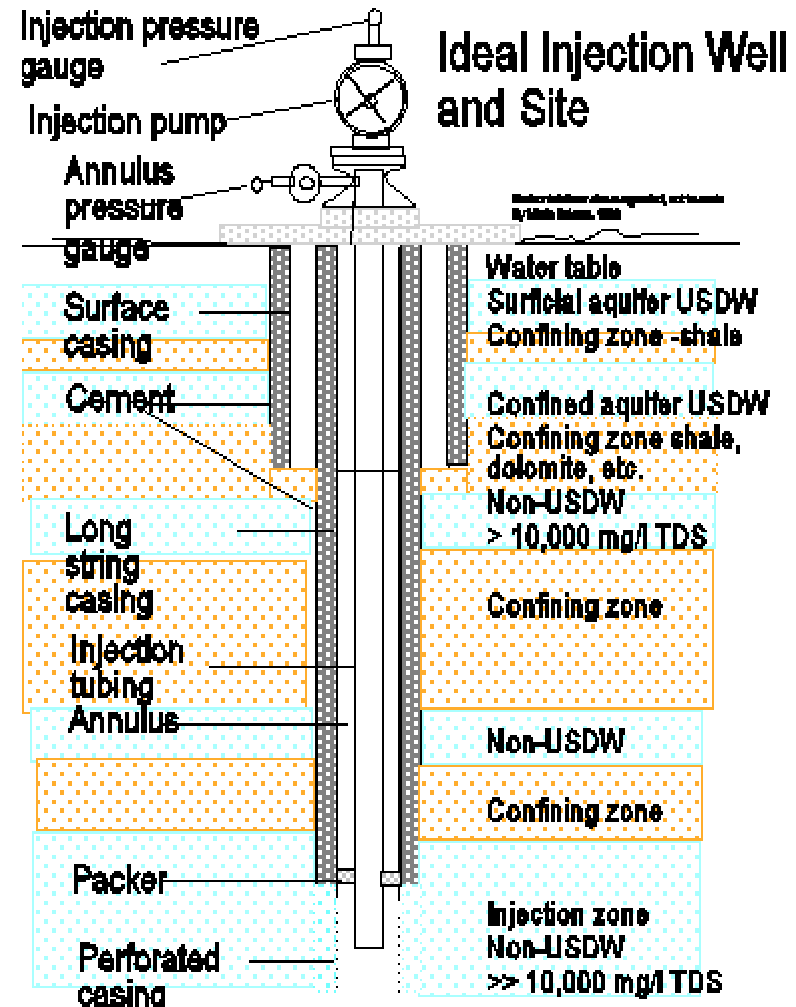
# Injection Operations—Siting, Design, and Construction of Class II Wells

- Siting

- Enough confining zones between the injection zone and the lowermost USDW
- No reasonable possibility of contamination

- Design and Construction

- No fluid can escape the injection string or can migrate in the bore-hole to a USDW
- The tubing should be set on a packer, the packer should be isolated and monitored for leaks, and the casing should be properly cemented on the outside



# ***Produced Water Cost***

- Costs range from <1¢ /bbl to several dollars/bbl
- Many factors contribute to cost

<b>Cost Component</b>	<b>Percentage</b>
Pumping	27
De-oiling	21
Lifting	17
Separation	15
Filtering	14
Injecting	5

Source: Khatib and Verbeek (2003)



# ***Components of Produced Water Cost***

- Site preparation
- Pumping
- Electricity
- Treatment equipment
- Storage equipment
- Management of residuals removed or generated during treatment
- Piping
- Maintenance
- Chemicals
- In-house personnel and outside consultants
- Permitting
- Injection
- Monitoring and reporting
- Transportation
- Down time due to component failure or repair
- Clean up of spills
- Other long-term liability.

# ***Costs for Offsite Commercial Disposal Facilities***

<b>State</b>	<b>Number of Facilities Using This Process</b>	<b>Type of Disposal Process</b>	<b>Cost<sup>a</sup></b>
CA	1	Evaporation/injection	\$0.01-\$0.09/bbl
KY	1	Injection	\$1/bbl
LA	23	Injection	\$0.20-\$4.50/bbl
NM	4	Evaporation	\$0.25-\$0.81/bbl
NM	1	Evaporation/injection	\$0.69/bbl
NM	1	Injection	\$0.69/bbl
OK	Eola Muds	Injection	\$0.30/bbl
PA	3	Treat/discharge	\$1-\$2.10/bbl
PA	1	Treat/POTW	\$1.25-\$1.80/bbl
PA	1	POTW/road spread	\$1.30-\$4.20/bbl
TX	9	Injection	\$0.23-\$4.50/bbl
UT	5	Evaporation	\$0.50-\$0.75/bbl
WY	10	Evaporation	\$0.50- \$2.50/bbl
WY	1	Treat/injection or discharge	\$0.96/bbl
WY	3	Injection	\$0.60-\$8.00/bbl

**Source: Veil (1997)**

# ***Rocky Mountain Region Produced Water Management Costs***

Management Option	Estimated Cost (\$/bbl)
Surface discharge	0.01-0.80
Secondary recovery	0.05-1.25
Shallow reinjection	0.10-1.33
Evaporation pits	0.01-0.80
Commercial water hauling	1.00-5.50
Disposal wells	0.05-2.65
Freeze-thaw evaporation	2.65-5.00
Evaporation pits and flowlines	1.00-1.75
Constructed wetlands	0.001-2.00
Electrodialysis	0.02-0.64
Induced air flotation for deoiling	0.05
Anoxic/aerobic granular activated carbon	0.083

Source: Jackson and Myers (2002, 2003)

# *Areas for Future Research*

- Management Options
  - Opportunities for water reuse
  - Treatment technologies for removing soluble organics
  - Energy-efficient injection technologies
- Analytical Methods
  - Improved standardized toxicity testing procedures
  - Improved assessment of impacts
- Risk and Impacts
  - Life-cycle analysis of produced water management options
  - Regulatory flexibility tied to actual risk
  - Less toxic treatment chemicals

# Conclusions

- The oil and gas industry generates huge volumes of produced water each year
  - Represents a significant cost for the industry
- Many alternatives are available for managing produced water



## *Conclusions (continued)*

- Companies must consider:
  - Volume of water generated
  - Chemical and physical characteristics
  - Regulatory requirements
  - Costs
  - Long-term liability of chosen options
- In a water-limited world, produced water can be a resource
- Additional research could open up new opportunities to manage produced water more effectively

